Using Vision for Animating Virtual Humans

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Visual Computing

- The field of Visual Computing is concerned with the analysis, numerical manipulation, querying, display, storage, and transmission of data.

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Application Domains

- Human Motion Analysis
- Biomedical Data Analysis
- Seismic Data Analysis

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Overview

- ✓ Motivation
- Theoretical Framework
  - Distributed Approximating Functionals
  - Physics-Based Modeling
- Human Motion Analysis
- Biomedical Data Analysis
- Conclusion

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Physics-Based Models: Computer Vision

- Objective
  - Represent nonrigid shapes
  - Reconstruct nonrigid shapes from noisy data
  - Estimate the motion of nonrigid objects
- Solution
  - Use the principles of physics to approximate the shape of objects and their behavior

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Physics-Based Models: Computer Graphics

- Objective
  - Model nonrigid objects and their interaction with the physical world
  - Realistically simulate and animate the motion of articulated objects with deformable parts
- Previous Attempts
  - Geometric modeling techniques have had limited success
- Solution
  - A mathematical representation of an object (or its behavior) which incorporates physical characteristics such as forces, torques and energies into the model allowing numerical simulation of its behavior.

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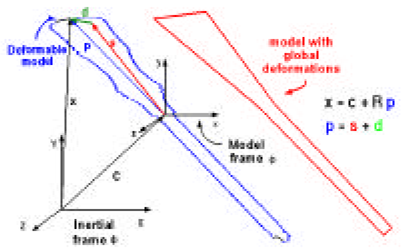
Geometry of Rigid/Deformable Models



Geometry: Global Deformations

- Geometric primitive: $\mathbf{e}(\mathbf{u}; a_1, a_2, \ldots)$
- Parameterized deformations:

$$\mathbf{T}(\mathbf{e}; b_1, b_2, \ldots)$$

- Global deformation parameter vector

$$\mathbf{s} = \mathbf{T}(\mathbf{e}(\mathbf{u}; a_1, a_2, \ldots); b_1, b_2, \ldots)$$

$$\mathbf{q}_s = (a_1, a_2, \ldots, b_1, b_2, \ldots)^T$$

Geometry: Global Deformations (cont.)

- Example: Superquadric

Geometry: Global Deformations (cont.)

- Example: Superquadric with deformation

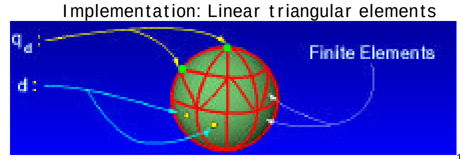
Geometry: Local Deformations

- Finite elements
  - Local deformation: **d**
  - Linear combination of nodal displacements:

$$\mathbf{d} = \mathbf{S}\mathbf{q}_d$$

S: Matrix of local finite element shape functions

Implementation: Linear triangular elements



Kinematics

- Generalized coordinate vector

$$\mathbf{q} = (\mathbf{q}_c^T, \mathbf{q}_\theta^T, \mathbf{q}_s^T, \mathbf{q}_d^T)^T$$

translation rotation global-def local-def

- Velocity of points on the model

$$\mathbf{x} = [\mathbf{I}\ \mathbf{B}\ \mathbf{RJ}\ \mathbf{RS}]\mathbf{q} = \mathbf{Lq}$$

- Jacobian $\mathbf{L}$ maps from $\mathbf{q}$-space to 3-space

Dynamics

- Lagrange equations of motion

Vision-Shape: $\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{f}_q$

Vision-Motion: $\ddot{\mathbf{q}} + \dot{\mathbf{q}} = \mathbf{f}_q$

Graphics: $\mathbf{M}\ddot{\mathbf{q}} + \mathbf{D}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{f}_q + \mathbf{g}_q$

$\mathbf{M}$: block symmetric mass matrix
$\mathbf{D}$: Raleigh damping matrix, $\mathbf{D} = a\mathbf{M} + b\mathbf{K}$
$\mathbf{K}$: stiffness matrix
$\mathbf{f}_q(\mathbf{u},t)$: generalized external forces
$\mathbf{g}_q(\mathbf{u},t)$: generalized inertial forces

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Dynamics: Generalized Forces

- Generalized external forces

$$\mathbf{f}_q = \mathbf{L}^T\mathbf{f} = \left(\underbrace{\mathbf{f}_c^{\,T}}_{\text{translation-f}}, \underbrace{\mathbf{f}_q^{\,T}}_{\text{rotation-f}}, \underbrace{\mathbf{f}_s^{\,T}}_{\text{global-f}}, \underbrace{\mathbf{f}_d^{\,T}}_{\text{local-f}}\right)^T$$

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Dynamics: Generalized Forces (cont.)

- Generalized inertial forces

$$\mathbf{g}_q = -\int \mu\, \mathbf{L}^T \dot{\mathbf{L}}\, \dot{\mathbf{q}}\, d\mathbf{u}$$

where

$$\dot{\mathbf{L}}\dot{q} = w \times (w \times \mathrm{Rp}) + 2w \times \mathrm{R}\dot{\mathrm{p}}$$

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Numerical Simulation of Motion Equations

- Second order system

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{D}\dot{\mathbf{q}} + \mathbf{K}\mathbf{q} = \mathbf{g}_q + \mathbf{f}_q + \mathbf{f}_{gc}$$

- Numerically integrate through time

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Motion-Based Part Segmentation

- **Given an image sequence of a multi-part object whose parts move relative to one another …**

  Recover a structured description in terms of moving parts, without a priori knowledge of the object or the object domain.

  Accurately estimate the parts' shape and motion parameters.

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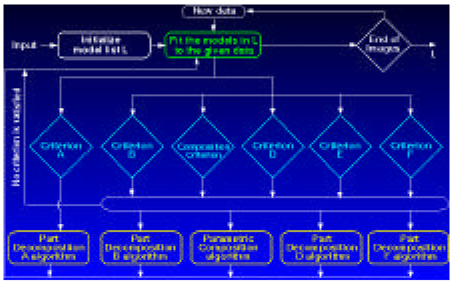
Part Segmentation Algorithm (PSA)



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Motion-Based Part Segmentation

Advantages

- Integrates the processes of part segmentation and fitting
- Allows reliable shape description of the parts
- Estimates the location of the joints between the parts (if any)
- Detects multiple joints
- Does not require an a priori model of the multi-part object or of the shape of the parts

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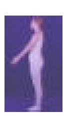
Contribution

- New framework for the two-dimensional part segmentation shape and motion estimation of multi-part objects.





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Human Model Acquisition

Given image sequences (from multiple views) of a moving human ...

Automatically segment the apparent contour and estimate the 2D shape of the subject's body parts (without a prior model for the human body or for the shape of the parts).

Automatically acquire a three-dimensional model of the subject's body parts.

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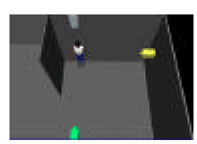
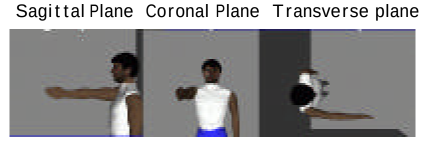
Experimental Setup



- Sagittal Plane Coronal Plane Transverse plane



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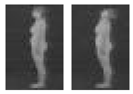
Human Body Model Acquisition

Protocol of movements: MovA

1. Head Motion



2. Left upper body extremities motions
3. Right upper body extremities motions

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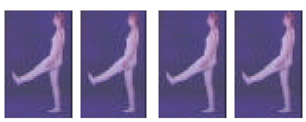
Human Body Model Acquisition

Protocol of movements: MovA (cont.)

4. Left lower body extremities motions
5. Right lower body extremities motions



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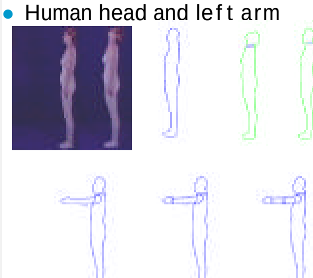
Results

- Human head and left arm



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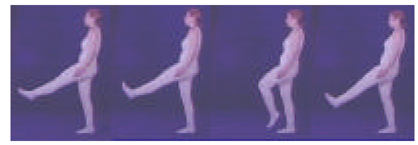
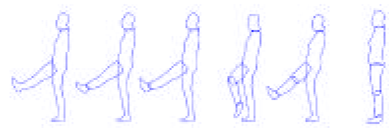
Results - Human leg





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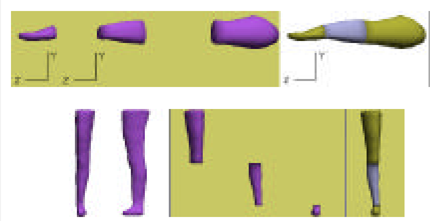
Results

- 3D models for the arm and the leg



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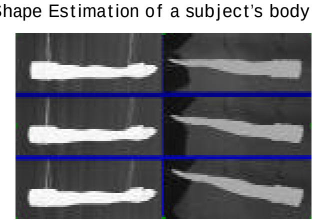
Validation and Performance Analysis

- 3D Shape Estimation of a subject's body parts



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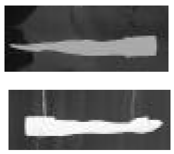
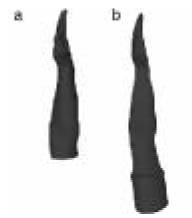
Validation and Performance Analysis

3D Shape Estimation of a subject's body parts





min error : 0.001 mm
max error : 3.736 mm
mean : 1.459 mm
std dev : 1.170 mm

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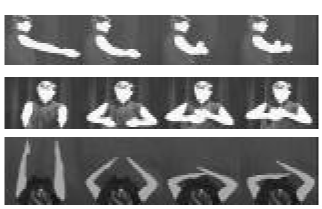
Human Motion Capture

Given image sequences of a moving human…
Estimate over time the 3D position and orientation of a subject's body parts.



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Challenges

- Humans perform complex 3D non-rigid motions
- Body parts may not be visible from certain viewpoints

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3D Model-based tracking

Input
- Image sequences of the moving human from three views, and
- The 3D models of the subject's body parts (as obtained with our method)

Output
- The 3D position and orientation over time of each of the subject's body parts

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Human Motion Capture

Advantages of our approach
- Obviates the need for markers or special equipment
- Model obtained from observations
- Mitigates difficulties arising due to occlusion among body parts
- Selects a subset of the cameras in an active and time varying fashion

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Model-Based Tracking: Steps

Steps
- Predict
- Select
- Match
- Update

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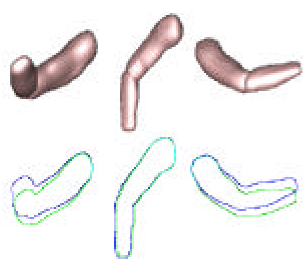
Model-Based Tracking: Select

Observability Index



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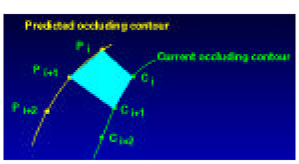
Model-Based Tracking: Select

Predicted occluding contour



Observability Index $(I) = \sum area(c_i, c_{i+1}, P_{i+1}, P_i)$

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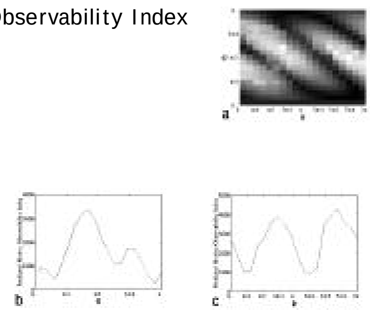
Model-Based Tracking: Select

- Observability Index



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Model-Based Tracking: Update

Lagrange equations of motion

$$\ddot{\mathbf{q}} + \dot{\mathbf{q}} = \mathbf{f}_q$$

where

$q(t)$: the generalized coordinate vector

$f_q(t)$: generalized external forces

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Model-Based Tracking: Predict

Extended Kalman Filter

$$\begin{bmatrix}\ddot{q}\\ \dot{q}\end{bmatrix} = \begin{bmatrix}-1 & 0\\ 1 & 0\end{bmatrix}\begin{bmatrix}\dot{q}\\ q\end{bmatrix}(t) + w(t)$$

$$z(t) = h\left(\begin{bmatrix}\dot{q}\\ q\end{bmatrix}(t)\right) + v(t)$$

$z(t)$: vector of observations

$h(t)$: nonlinear function which relates the input data to the model's state

$w(t)$: modeling error

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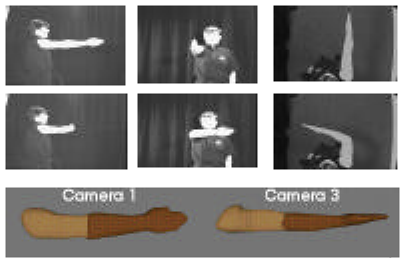
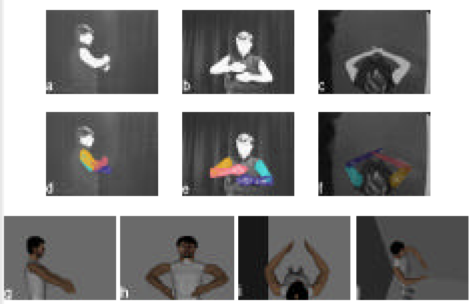
Human Body Model Acquisition

Frame	Camera1	Camera2	Camera3
001			
035			

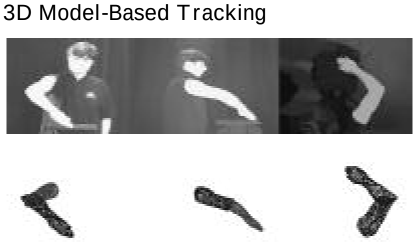


Human Motion Capture



Validation and Performance Analysis

3D Model-Based Tracking



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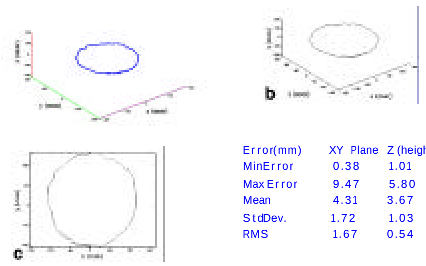
3D Model-Based Tracking

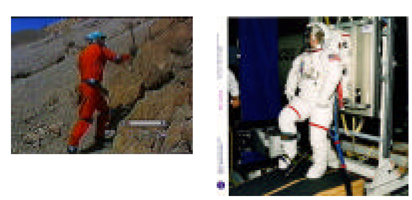


Error(mm)	XY Plane	Z (height)
MinError	0.38	1.01
Max Error	9.47	5.80
Mean	4.31	3.67
StdDev.	1.72	1.03
RMS	1.67	0.54

Video Presentation

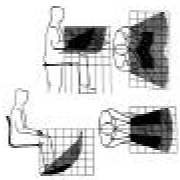
Tracking Using Monocular Images

- There are several applications for which the video recordings from only one view are available



Motivation

- Performance measurement for human factors engineering



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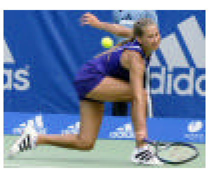
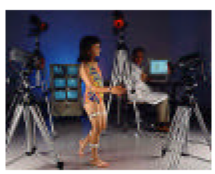
Motivation (Cont.)

- Posture and gait analysis for training athletes and physically challenged individuals





http://www.motionanalysis.com

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Motivation (Cont.)

- Human body, hands and face animation

http://ligwww.epfl.ch/

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Motivation (Cont.)

- Automatic annotation of human activities in video databases

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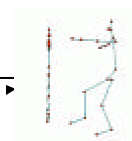
Problem Statement

Given a set of points in an image that correspond to the projection of landmark points of a human subject …

estimate both the anthropometric measurements (up to a scale) of the subject and his/her pose that best match the observed image

Image →  ← 3D Human Model

(up to scale)

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Our Approach

Novelty

✓ Using anthropometric statistics to constrain the estimation process

Advantages

✓ Estimation of both anthropometry and pose simultaneously

✓ Able to estimate anthropometry and pose from a single image

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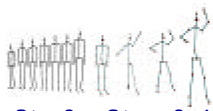
Overview

Novelty: Using anthropometric statistics to constrain the estimation process



Step 1

Selection of projected landmarks on the image

Step2 Steps 3, 4 ...

- Initial Anthropometric Estimates
- Initial Pose Estimates
- Iterative Minimization over lengths and angles

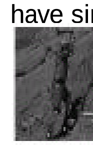
Output

Human model

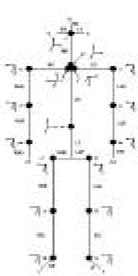
Step 1: Selection of projected landmarks

Through a simple interface, the user:

- Selects the projection of visible landmarks of the subject's body
- Marks
  - segments whose orientation is almost parallel to the image plane
  - pairs of segments that have similar orientation



Human Body Model



ID	Joint	From	To	DOF	PR
at	atlanto occipital	NK	HD	Tz*Rz*Ry*Rx	3
sp	solar plexus	UT	NK	Tz*Ry*Rz*x	2
la	left ankle	LLL	LF	Tx*Rz*Rx*Ry	4
lc	left clavicle	UT	LC	Tz*Rx*Ry	3
le	left elbow	LUA	LLA	Tz*Ry	5
lh	left hip	LT	LUL	Tz*Rz*Rx*Ry	2
lk	left knee	LUL	LLL	Tz*R-y	3
ls	left shoulder	LC	LUA	Tz*Rz*Rx*Ry	4
lw	left wrist	LLA	LHD	Tz*Ry*Rx*Rz	6
ra	right ankle	RLL	RF	Tx*R-z*R-x*Ry	4
rc	right clavicle	UT	RC	Tz*R-x*Ry	3
re	right elbow	RUA	RLA	Tz*Ry	5
rh	right hip	LT	RUL	Tz*R-z*R-x*Ry	2
rk	right knee	RUL	RLL	Tz*R-y	3
rs	right shoulder	RC	RUA	Tz*R-z*R-x*Ry	4
rw	right wrist	RLA	RHD	Tz*Ry*R-x*R-z	6
wt	waist	LT	UT	Tz*Ry*Rz*Rx	1

- 22 segments, 17 joints and 64 DoF

Output

- Image coordinates of the selected projected landmarks
- a set of ratios (of projected lengths) using the segments selected by the user

Family of Human Body Models

- 2187 human body models based on anthropometric statistics

- The cadre family is a representation of the population distribution which spans the space to capture a significant amount of the variance

Step 2: Initial Anthropometric Estimates

Input: a set of ratios using the segments selected by the user

Output: the initial human model q^* from our cadre family of 2187 human models.

$$q^* = \arg\min_{q=1,\ldots,139} \sum_{i,j\in I} \left(r_{ij}^q - p_{ij}\right)^2$$

where $r_{ij}^q = \frac{l_i^q}{l_j^q}, i<j$ are the ratios of the segments of each cadre family member that correspond to the segments selected

Steps 3 and 4: Estimates for pose and anthropometry

Goal

- ✓ Minimize the discrepancy between the synthesized appearance of the Stick Model (for that pose) and the image data of the subject in the given image

$$\min f(x_j)$$
$$L_j \le x_j \le U_j,\ j = 1,\ldots,K$$

where x_j can be an angle or a length or a ratio, and L_j and U_j are its lower and upper values.

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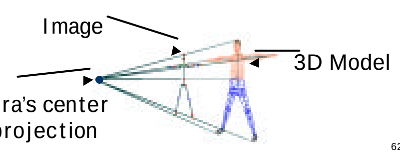
The Objective Function

- The sum of squared distances between the Stick model's site and the closest point from the line formed by the camera's center of projection and its corresponding landmark



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Minimization process

To guide the minimization process to a solution for a pose that is anthropometrically plausible, we apply:

- ✓ a geometric method for the initial pose estimation
- ✓ a hierarchical solver
- ✓ various constraints

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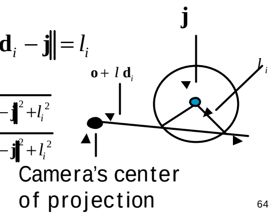
Initial Pose Estimates

We use a geometric method for providing two initial guesses for the pose of some segments as follows:

$$\|\mathbf{o} + l\,\mathbf{d}_i - \mathbf{j}\| = l_i$$

Solutions

$$l_1 = \mathbf{d}_i \cdot (\mathbf{j}-\mathbf{o}) + \sqrt{[\mathbf{d}_i \cdot (\mathbf{j}-\mathbf{o})]^2 - \|\mathbf{o}-\mathbf{j}\|^2 + l_i^2}$$
$$l_1 = \mathbf{d}_i \cdot (\mathbf{j}-\mathbf{o}) - \sqrt{[\mathbf{d}_i \cdot (\mathbf{j}-\mathbf{o})]^2 - \|\mathbf{o}-\mathbf{j}\|^2 + l_i^2}$$



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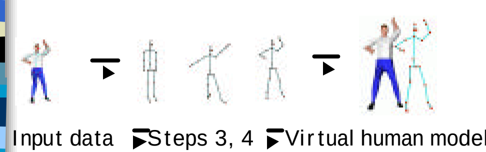
Hierarchical Solver

We assign a priority to each joint and site, and we schedule the optimization process



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Constraints

Three classes of constraints are applied:

- Constraints derived from the joint limit information associated with the range of motion of each joint,
- Constraints that enforce the symmetry between the left and right sides of the subject, and
- Constraints that enforce proportions.

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Results

Synthetic Experiment

Accuracy

	$\frac{LC}{UT+LT}$	$\frac{LLA}{LUA}$	$\frac{LHP}{LUA}$	$\frac{LF}{LUL}$	$\frac{LF}{LUL}$
Actual	0.6553	0.9829	0.5700	0.6397	0.6341
Estimated	0.6517	0.9781	0.5713	0.6377	0.6329
PE %	0.5494	0.4810	0.2281	0.3090	0.1876

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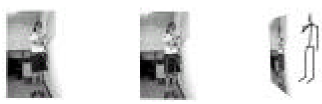
Results

Subject: Vannesa



Accuracy

	$\frac{LC}{UT+LT}$	$\frac{LLA}{LUA}$	$\frac{LHP}{LUA}$	$\frac{LF}{LUL}$	$\frac{LF}{LUL}$
Actual	0.6279	0.8625	0.6949	0.5517	0.4778
Estimated	0.6266	0.8516	0.6925	0.5468	0.4767
PE %	0.1958	1.2638	0.3180	0.8957	0.2302

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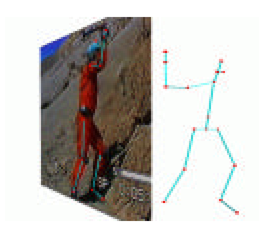
Results

- Field work



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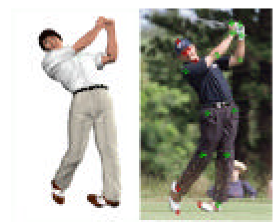
Results

- Golfer



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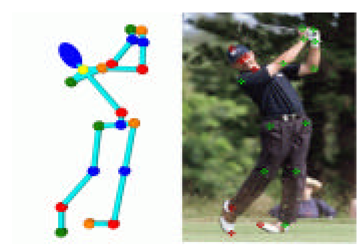
Golf



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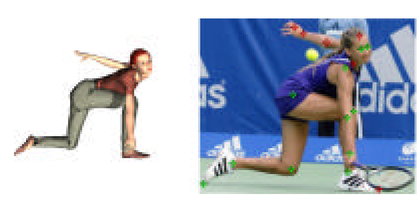
Results

- Tennis Player



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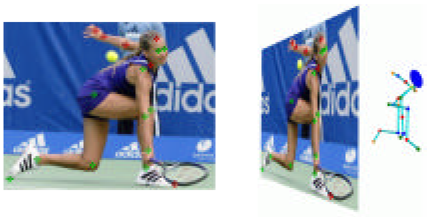
Tennis



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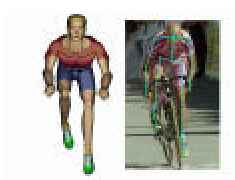
Results

- Cyclist



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VER I

Research Thrusts

- Intelligent Systems
- Computational Biomedicine
- Biomedical Robotic Systems
- Geophysical Data Analysis and Visualization

Analysis,Modeling, Simulation, Visualization
Multimodal Human Computer Interaction

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Conclusions

- "We live in interesting times"
- Abundance of sensors
- Large volumes of information rich data
- New efficient and robust methods for analyzing, querying, visualizing and storing data

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Our Team

- **Post-Doc**
  - Geovanni Martinez
- **Ph.D. Students**
  - Carlos Barron
  - Amol Pednekar
- **M.S. Student**
  - Anthony Do
- **Undergraduate Student**
  - Vanessa Zavaletta

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